ICES Journal of Marine Science, 53: 297–302. 1996

Lateral target strength of Antarctic krill

Roger P. Hewitt and David A. Demer

Hewitt, R. P. and Demer, D. A. 1996. Lateral target strength of Antarctic krill. – ICES Journal of Marine Science, 53: 297–302.

An area of high krill (*Euphausia superba* Dana) density was continuously monitored with down-looking and side-looking sonars over a period of 24 h. Measurements of volume backscattering strength were used to describe the density of krill with depth and the vertical movement of krill over time. *In situ* measurements were made of dorsal aspect target strength (TS) and, as krill moved into the near-surface layer (0–15 m), *in situ* measurements were made of lateral-aspect TS. The probability density function (PDF) of TS measurements made with the down-looking transducer had a mode at approximately −73 dB. The PDF of TS measurements made with the side-looking transducer was broader with a mode at approximately −67 dB. Sampled krill had a bi-modal length distribution with a major mode at 44 mm and a minor mode at approximately 30 mm.

Key words: acoustic target strength, Antarctic krill, *Euphausia superba*.

R. P. Hewitt and D. A. Demer: Southwest Fisheries Science Center, PO Box 271, La Jolla, California 92038, USA. Correspondence to Hewitt and Demer [tel: +1 619 546 5600, fax: +1 619 546 7003].

Introduction

Acoustic surveys of Antarctic krill (*Euphausia superba* Dana) are biased when the animals migrate above the observation window of down-looking transducers (Demer, 1994). Although the major portion of krill biomass is concentrated above 150 m, Miller and Hampton (1989) estimated that 40% could be concentrated in the uppermost 5 m at night. Three approaches to minimizing this bias are: (1) surveying only during the hours when the krill reside within the ensonified range; (2) adjusting the observed density observations with a temporal compensation factor (Demer and Hewitt, 1995); and (3) directly estimating the abundance of krill in the near-surface layer using side-looking sonars.

The use of side-looking sonars for quantitative surveys requires knowledge of the reflective properties of krill when ensonified from the side (Everson and Bone, 1986). This paper presents a set of *in situ* measurements of lateral aspect target strength (TS) of krill at 120 kHz. These data may be useful in interpreting measurements of volume backscattering strength made with a calibrated side-looking echo-sounder.

To convert measurements of volume backscattering strength to estimates of animal density, recent analyses of acoustic surveys for krill have used an empirical model of krill TS, derived only as a function of animal length (Greene *et al.*, 1991; Hewitt and Demer, 1993; Trathan *et al.*, 1995). However, this model does not explicitly account for animal orientation relative to the ensonifying beam. Calculations made by several investigators (Greenlaw *et al.*, 1980; Sameoto, 1980; Stanton *et al.*, 1993; Demer and Martin, 1995) indicate that changes in animal orientation may be the largest source of variability. Additional variability in observed TS measurements may result from incorrectly judging multiple animals within the sampling volume as single individuals (Hewitt and Demer, 1991). A threshold bias is also possible when valid TS measurements from single animals cannot be distinguished from noise; average TS derived from measurements of individual scatterers may be thus overestimated (Foote *et al.*, 1993). For these reasons, lateral aspect *in situ* TS measurements are presented as a probability density function (PDF) and compared with the PDF of dorsal aspect TS measurements recorded concurrently.

Methods

A surface float was drogued at 15 m depth and set adrift approximately 10 km north of Elephant Island, Antarctica in an area of high krill density. Surveying with down-looking and side-looking sonars, acoustic data were collected within 1 km of the buoy over a 24 h period on 10–11 March 1994. Measurements of volume backscattering strength described the vertical movement of krill over time. *In situ* measurements were made of

1054–3139/96/020297+06 $18.00/0

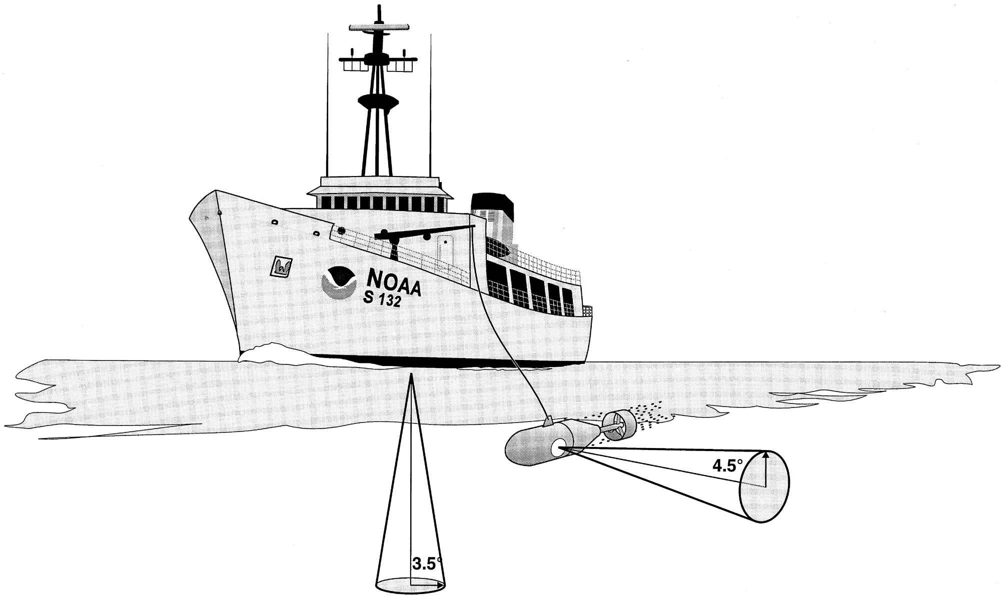

Figure 1. Configuration of transducers showing side-looking 120 kHz split-beam transducer deployed in a dead weight towed body and a down-looking 120 kHz split-beam transducer mounted in a blister extending approximately 0.5 m from the hull of the ship.

dorsal aspect TS and, as krill moved into the near-surface layer (0–15 m), *in situ* measurements were made of lateral aspect TS. System calibrations were performed before and after the experiments at Ezcura Inlet, King George Island, Antarctica (Demer *et al.*, submitted).

TS measurements were made with two 120 kHz split-beam transducers: one mounted on a faired blister extending approximately 0.5 m from the hull of the ship (5.1 m from the water surface), the other mounted in a towed body (7–10 m from the water surface) and oriented to be side-looking (Fig. 1). Both transducers were narrow beam and circularly symmetrical with 7° and 9° between half-power points, respectively. The pulse length was 0.3 ms, implying that krill had to be separated by at least 0.22 m in range to be delineated as single targets (Ehrenberg, 1989).

TS measurements of individuals were achieved using a single-target detection algorithm (Bodholt *et al.*, 1989). To increase the likelihood of single-target detections, a multi-tiered algorithm was used to discriminate against multiple scatterers and noise. Filters were imposed on the minimum and maximum normalized echo length (0.8 and 1.8, respectively), the minimum allowable TS (-90 dB), the maximum off-axis angle (6°) and maximum electrical phase jitter between samples inside the echo pulse (5.625°). Using the split-beam position information, beam-pattern effects were removed from all measurements.

An Isaacs-Kidd Midwater Trawl (IKMT) was used to collect krill specimens at the end of the experiment (Devereaux, 1953). The IKMT had a mouth opening of 5.2 m^2 and was outfitted with a net made of approximately 20 mm mesh nylon tapering to 2 mm mesh at the codend.

Results

Target strengths measured with both the down-looking and side-looking transducers increased with increasing range (Fig. 2a, c), indicating a range-dependent bias. Two factors contribute to this bias: (1) the inherent ability of the instrument to distinguish weak targets decreases with range causing a ''threshold bias'' (Foote *et al.*, 1993); and (2) a range-dependent increase in TS values, approximately proportional to the increase in sample volume, which may also be expected if the bias is caused by multiple targets falsely identified as individuals (Hewitt and Demer, 1991; Demer, 1994; Soule *et al.*, 1995). For a krill swarm with a homogeneous density, a larger sampling volume will contain proportionately more animals than a smaller sampling volume. Therefore, a misjudged TS measurement from a larger sampling volume is likely to include more scatterers than a misjudged measurement from a smaller volume.

The probability of accepting multiple targets as individuals was reduced by only including TS measurements at ranges less than 25 m (Fig. 3a, c). The sample volume was further reduced by restricting consideration to those targets less than 3° off the axis of the acoustic beam (see Figs 2b, d and 3b, d).

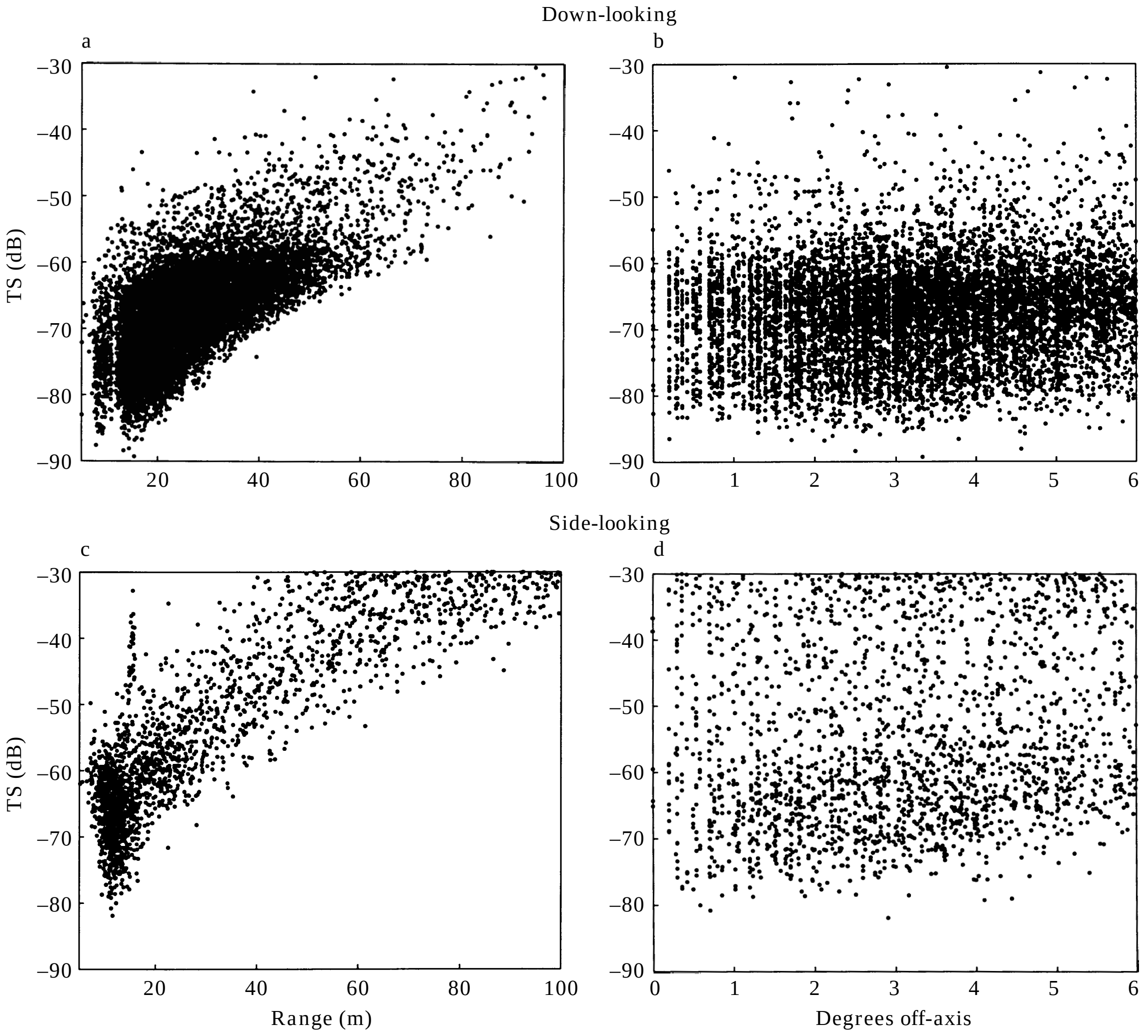

Figure 2. Down-looking (a and b) and side-looking (c and d) *in situ* measurements of TS versus range from the transducers (a and c) and versus angle off the axes of the acoustic beams (b and d). Approximately 12 000 measurements of TS were made with the down-looking transducer, and approximately 7200 measurements were made with the side-looking transducer.

The probability density function (PDF) of TS measurements made with the down-looking transducer had a mode at approximately −73 dB (Fig. 4b). The PDF of TS measurements made with the side-looking transducer was broader with a mode at approximately −67 dB (Fig. 4d). The PDFs for the TS measurements expressed as echo amplitude had single modes (Fig. 4a, c), indicative of a uni-modal length-frequency distribution. The mode for side-looking echo-amplitude measurements was higher and broader than that for down-looking.

The length-frequency distribution for the krill caught with the IKMT was bimodal with modes at approximately 30 and 44 mm; however, the distribution was dominated by the larger size class (Fig. 5).

Discussion

Animal orientation with respect to the axis of the sound beam can have a profound effect on TS (Stanton *et al.*, 1993). Among individual euphausiids within an aggregation, the vertical angle of inclination can be expected to vary less than the horizontal angle of orientation. Kils (1981) estimated the average angle of inclination for Antarctic krill to be 45.3°. Endo (1993) observed captive krill and reported an average angle of inclination of 45.6° with a standard deviation of 19.6°. In contrast, the horizontal angle of orientation with respect to the axis of the sound beam can range from 0° to 360°.

Assuming that krill reflect sound equally when ensonified perpendicularly from above or from the

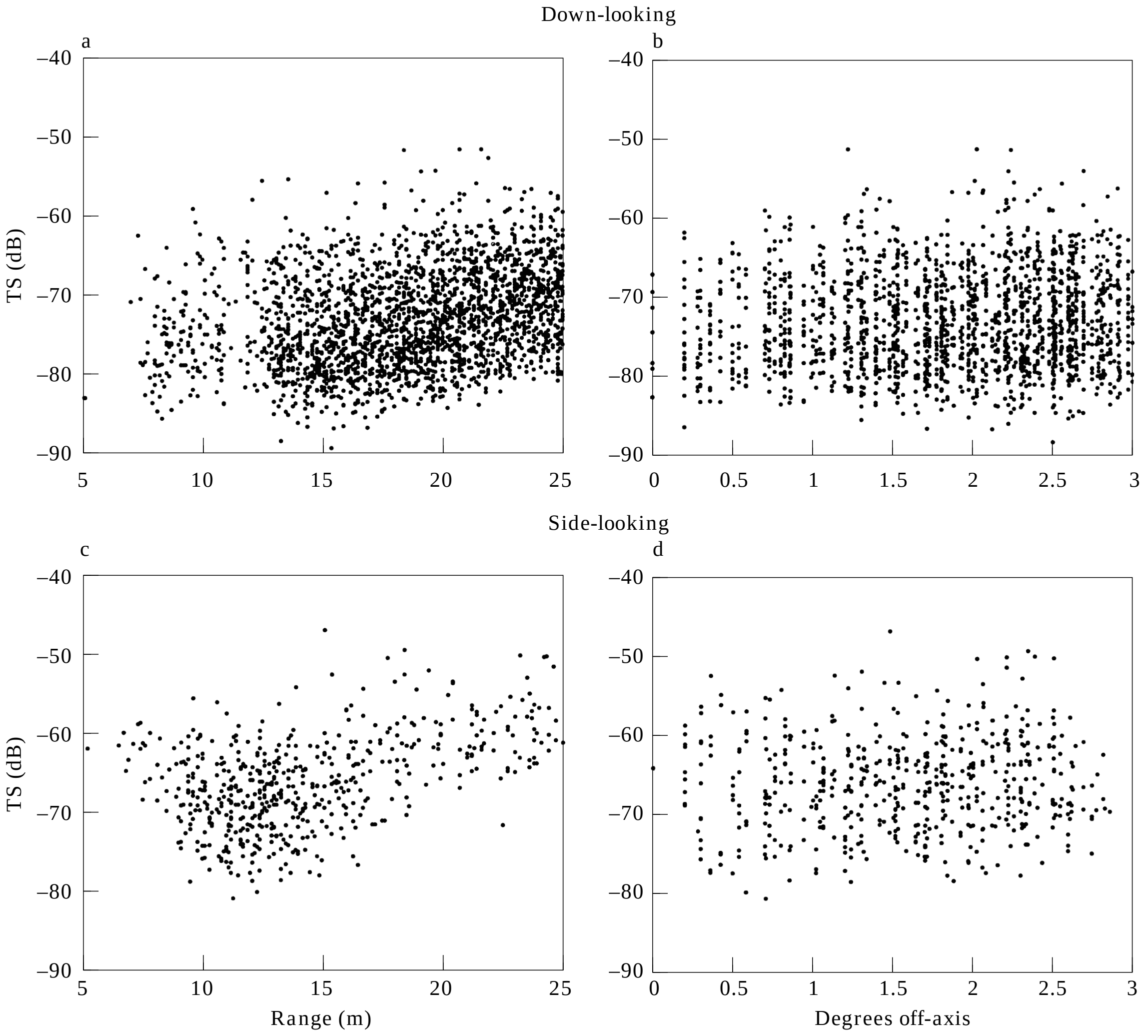

Figure 3. Trimmed data sets of down-looking (2478) and side-looking (549) *in situ* measurements of TS versus range from the transducers (a and c) and versus angle off the axes of the acoustic beams (b and d).

side at 120 kHz, then the difference in modal TS may be explained by the angle of orientation to the sound beam and the threshold of detection. When viewed from above, krill are not, on average, orthogonal to the sound beam. When viewed from the side, however, they have an equal chance of being orthogonal to the sound beam as any other angle. In addition, any flexure of the body should reduce dorsal aspect TS, but have little effect on lateral aspect TS. Therefore, the echo-sounder will detect a higher proportion of strong targets from the side-looking transducer as it will from the down-looking transducer. This effect will be compounded by the limited ability of the echo-sounder to distinguish weak targets. The expected result would be a broader PDF with a higher mode for lateral aspect TS measurements than the PDF for dorsal aspect TS measurements.

The TS measurements presented here agree with these expectations. Accordingly, the PDF of side-looking measurements of volume backscattering should have a higher and broader mode than those made with a down-looking transducer on the same (or similar) aggregations of krill.

Two options are available for estimating animal density from side-looking measurements of volume backscattering: (1) divide by the observed PDF of backscattering cross-section (inferred from TS), or (2) divide by a PDF of backscattering cross-section calculated from a model incorporating a PDF of observed animal lengths and a uniform PDF of horizontal angle of orientation (e.g. Stanton *et al.*, 1993; Chu *et al.*, 1993).

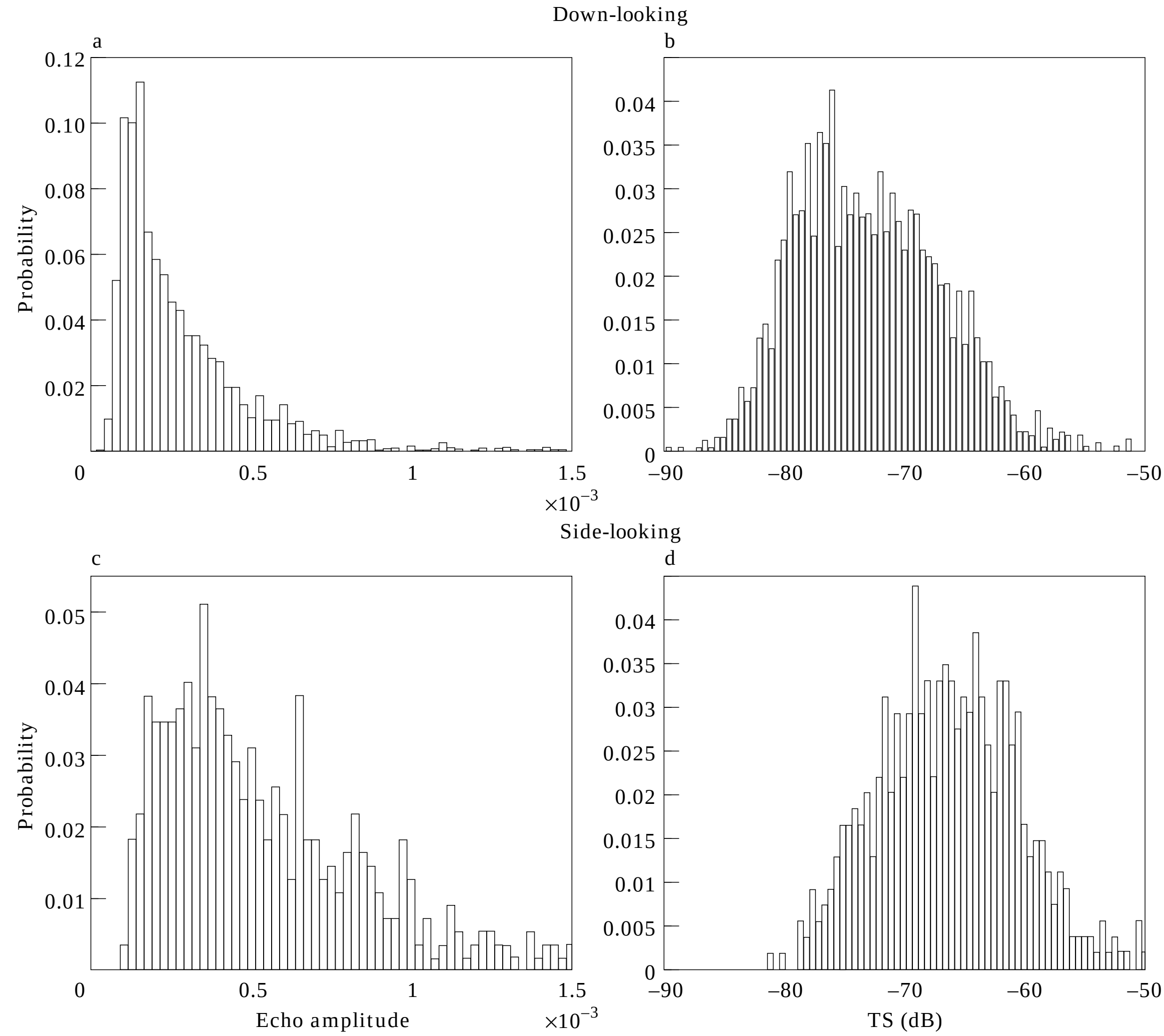

Figure 4. Probability density functions (PDF) of *in situ* measurements of target echo amplitude (a and c) and TS (b and d). Note differing scales.

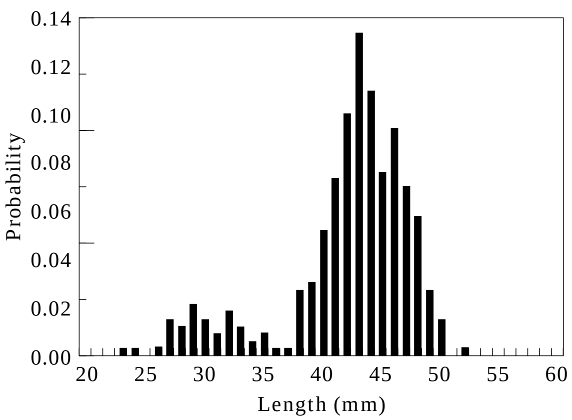

Figure 5. Length-frequency distribution of krill caught with an Isaacs-Kidd Midwater Trawl (IKMT) in conjuction with the acoustic observations.

Acknowledgements

We are grateful to Nick Carbone and Jane Rosenberg, who helped us collect the data, to David Greene and King Claggett, who rigged and deployed the drogued buoy, and to the Captain and officers of NOAA Ship Surveyor, who maintained our position relative to a moving reference point. This work was sponsored by the US Antarctic Marine Living Resources (AMLR) program.

References

Bodholt, H., Nes, H., and Solli, H. 1989. A new echo-sounder system. Proceedings IOA, 11: 123–130.

Chu, D., Foote, K. G., and Stanton, T. K. 1993. Further analysis of target strength measurements of Antarctic krill at

38 and 120 kHz: comparison with deformed cylinder model and inference of orientation distribution. Journal of the Acoustical Society of America, 93: 2985–2988.

Demer, D. A. 1994. Accuracy and precision of echo integration surveys of Antarctic krill. PhD thesis. Scripps Institution of Oceanography, University of California, San Diego. 144 pp.

Demer, D. A. and Hewitt, R. P. 1995. Bias in acoustic biomass estimates of *Euphausia superba* due to diel vertical migration. Deep-Sea Research, 42: 455–475.

Demer, D. A., Hewitt, R. P., and Loeb, V. J. (Submitted). In situ target strength measurements of Antarctic zooplankton (*Euphausia superba* and *Salpa thompsoni*) at 120 and 200 kHz, corroboration of scattering models, and a statistical technique for delineating species. Journal of the Acoustical Society of America.

Demer, D. A. and Martin, L. V. 1995. Zooplankton target strength: volumetric or areal dependence? Journal of the Acoustical Society of America, 98: 1111–1118.

Devereaux, R. F. 1953. Isaacs-Kidd midwater trawl. Scripps Institution of Oceanography, Reference 53(3). 21 pp.

Ehrenberg, J. E. 1989. A review of target strength estimation techniques. Underwater Acoustical Data Processing, pp. 161–176. Ed. by Y. T. Chan. Kluwer, Dordrecht.

Endo, Y. 1993. Orientation of Antarctic krill in an aquarium. Nippon Suisan Gakkaishi, 59: 465–468.

Everson, I. and Bone, D. G. 1986. Detection of krill (*Euphausia superba*) near the sea surface: preliminary results using a towed upward-looking echo-sounder. British Antarctic Survey Bulletin, 72: 61–70.

Foote, K. G., Chu, D., and Stanton, T. K. 1993. Status of krill target strength. CCAMLR Selected Scientific Papers, Commission for the Conservation of Antarctic Marine Living Resources, Hobart Tasmania, SC-CAMLR-SSP/9: 101–126.

Greene, C. H., Stanton, T. K., Wiebe, P. H., and McClatchie, S. 1991. Acoustic estimates of Antarctic krill. Nature, 349: 110.

Greenlaw, C. F., Johnson, R. K. and Pommeranz, T. 1980. Volume scattering strength predictions for Antarctic krill (*Euphausia superba* Dana). Meeresforsch, 28: 48–55.

Hewitt, R. P. and Demer, D. A. 1991. Krill abundance. Nature, 353: 310.

Hewitt, R. P. and Demer, D. A. 1993. Dispersion and abundance of Antarctic krill in the vicinity of Elephant Island in the 1992 austral summer. Marine Ecology Progress Series, 99: 29–39.

Kils, U. 1981. Swimming behavior, swimming performance and energy balance of Antarctic krill, *Euphausia superba*. BIOMASS Scientific Series, 3: 122 pp.

Miller, D. G. M. and Hampton, I. 1989. Biology and ecology of the Antarctic krill. BIOMASS Scientific Series, 9: 1–166.

Sameoto, D. D. 1980. Quantitative measurements of euphausiids using a 120 kHz sounder and their in situ orientation. Canadian Journal of Fisheries and Aquatic Sciences, 37: 693–702.

Soule, M., Barange, M., and Hampton, I. 1995. Evidence of bias in estimates of target strength obtained with a split-beam echo-sounder. ICES Journal of Marine Science, 52: 139–144.

Stanton, T. K., Chu, D., Wiebe, P. H., and Clay, C. S. 1993. Average echoes from randomly oriented random-length finite cylinders: zooplankton models. Journal of the Acoustical Society of America, 94: 3463–3472.

Trathan, P. N., Everson, I., Miller, D. G. M., Watkins, J. L., and Murphy, E. J. 1995. Krill biomass in the Atlantic. Nature, 373: 201–202.